

Developments in high-density Cobra fiber positioners for the Subaru Telescope's Prime Focus Spectrometer

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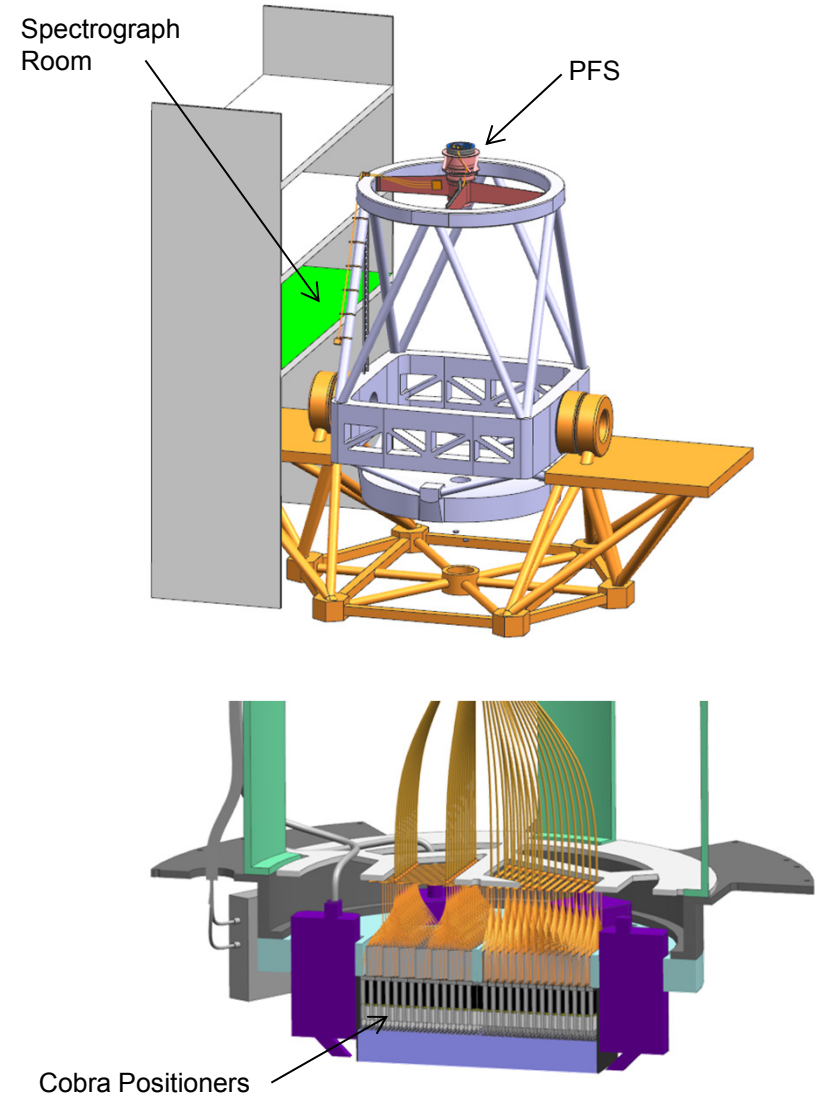


Outline

- Description of the Prime Focus Spectrometer (PFS)
 - Focal Plane layout
- Cobra positioner design overview
 - Key Requirements
- Recent design changes
 - Hard Stops
 - Manufacturing/Assembly
- Latest performance testing
 - Test set up
 - Performance comparison (2012 vs. 2009)
- Path forward

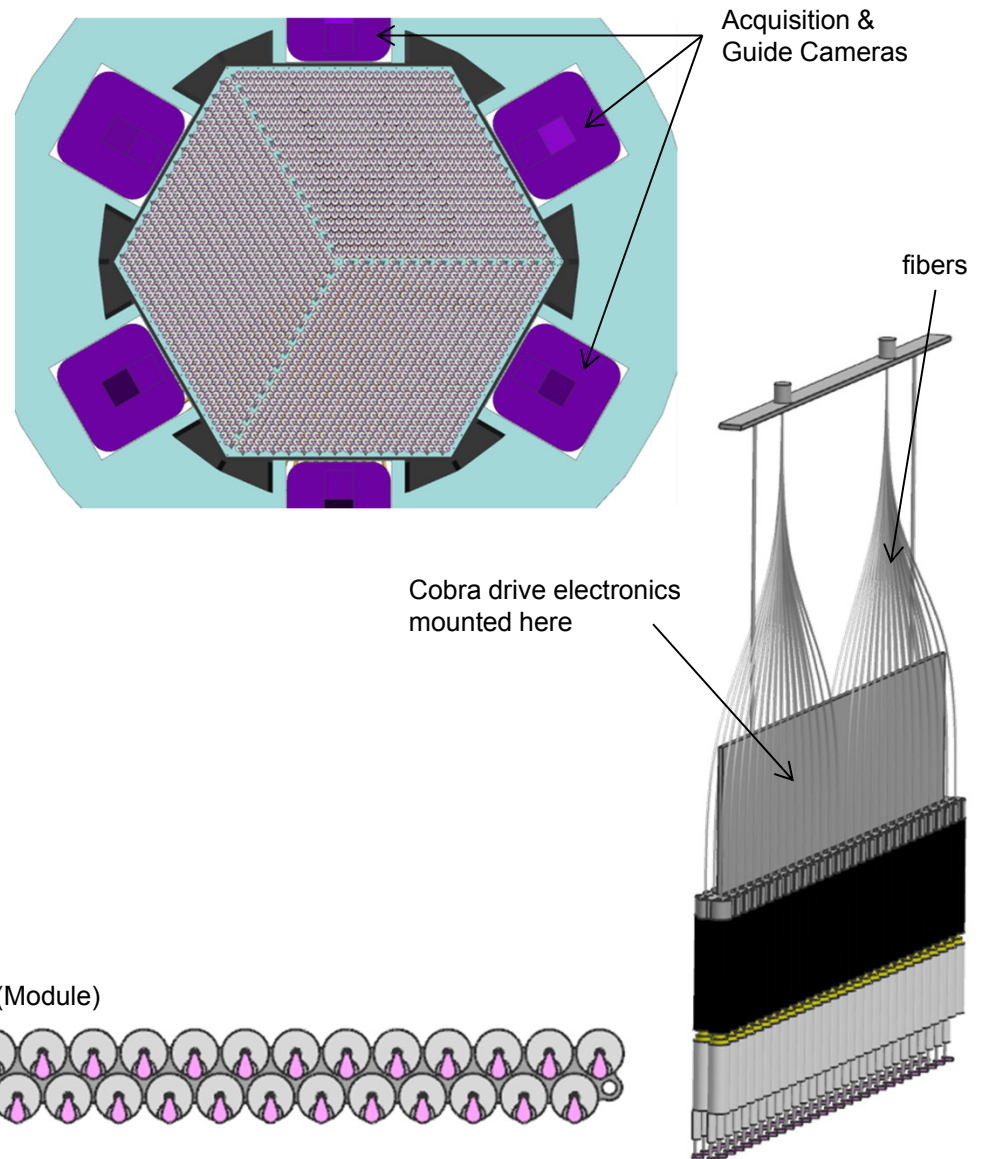
Prime Focus Spectrometer

- PFS is a multi-object fiber-fed spectrometer that will conduct targeted surveys for the study of dark energy, galaxy evolution and galactic archaeology
 - Evolved from Wide-Field Multi Object Spectrometer (WF MOS)
- Consists of 2394 fibers (-f/2.4) arranged in a 1.38 degree field at the prime focus of the Subaru Telescope
- The light from each cosmological target is fed through ~50m of fiber to a spectrograph located off of the telescope
- Key to the instrument is the Cobra fiber positioner that can rapidly position an individual fiber to within 5 μ m of the intended target in 1 minute



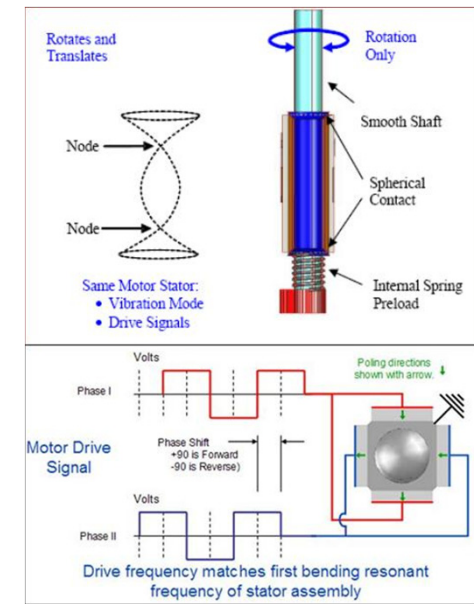
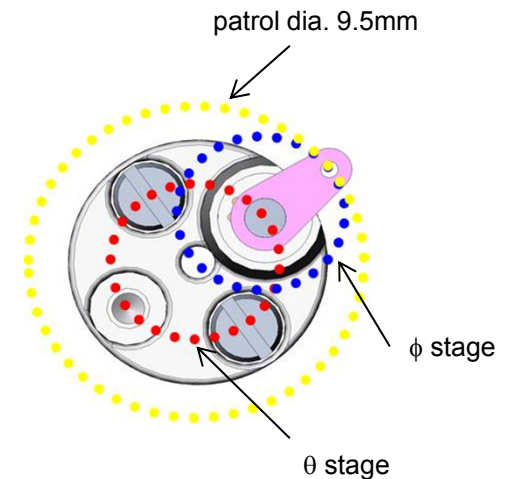
Focal Plane Configuration

- Within 1.38° FOV
 - 2394 Cobra positioners
 - 6 acquisition & guide cameras
 - 85 fiducial fibers
- Cobra positioners are hex packed with 8mm center-to-center spacing
- Assembled into 42 modules that contain 57 Cobra positioners each
 - 1 row of 28, 1 row of 29
 - Each module contains the drive electronics necessary to run the 114 motors.
- They are arrayed to create 3 parallelograms with spaces between allowing for the placement of 43 fiducial fibers in the array and 42 fiducial fibers around the perimeter of the array.



Cobra Design Overview

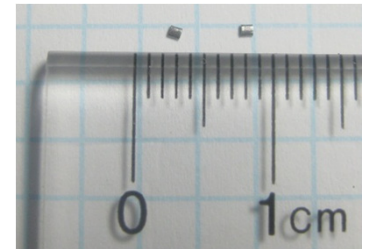
- Cobra is a θ , ϕ configured mechanism that contains 2 piezo rotary motors offset from each other by $\frac{1}{4}$ of the desired patrol diameter.
 - Theta-stage is 4.4mm wide motor
 - Phi-stage is 2.4mm wide motor
- Patrol diameter is sized so that there is overlap with all adjacent positioners to provide full coverage of the focal plane.
- Fiber is routed from the arm on the phi-stage through the center of the Cobra
 - Stages utilize floating hard stops to allow for full range of motion, yet prevent over twisting of the optic fiber
 - Protects fiber during handling and operation
- Piezo motors use phase shifted signals to excite the motor body at the first bending resonant frequency
 - Stick-slip conditions between the motor stator and end caps on the output shaft creates rotary motion.



Courtesy NST

Design Changes

- Hard Stops
 - The floating hard stops were identified as a contributor to positioning errors and erratic behavior based on testing the original prototype in 2009
 - Phi-stage hard stop had propensity to fall out or dislodged during basic handling
 - Both hard stops would occasionally get cocked and slow the motors down
 - Phi-stage hard stop was switched to a static hard stop limiting travel from -20° to $+200^{\circ}$
 - Theta-stage hard stop was kept as floating, but the aspect ratio was increased to help reduce the likelihood of rotating and jamming
- Design for Manufacturability and Assembly
 - Reduce the number of bonding operations required for assembly
 - Replace with set screws/clamps
 - Eliminates waiting for cure times
 - Use flex print cables for both motors
 - Easier routing of cables from the motors down the outside of the Cobra housing
 - Low profile to allow for dense packing
 - Cable loop built into the base of the phi-stage
 - Change in ceramic end cap vendor
 - Tighter control of surface finishes and run out
 - Reduced scrap rate and need for hand polishing parts
 - Unit cost reduction was not realized when producing just 5 Cobra positioners
 - Based upon vendor quotes – cost savings will be realized on large quantity builds



2009 phi-stage floating hard stop

Performance Testing – Set Up

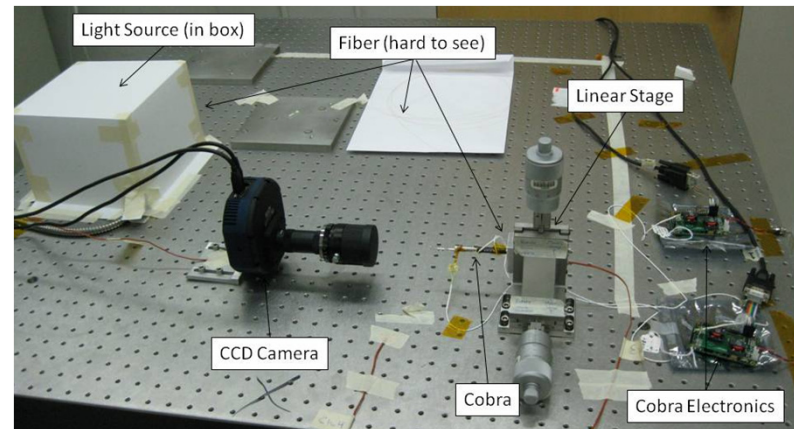
- New Scale Technologies delivered 5 new prototype Cobra positioners in the spring 2012
- Intent was to evaluate performance of “upgrades” to the design against the original test results from 2009
- Requirement: converge on a 90% of all targets to within 5 μ m in 10 move iterations or less

Mimic how PFS will function

1. Back-light fibers - image using metrology camera
2. Centroided fiber images determine current location in pixel space
3. Calculate motor angles using inverse kinematics
4. Predict number of motor steps needed to move desired angles
5. Command Cobra to move
6. Back-light fibers – image using metrology camera
7. Etc.
8. Etc.

Test Set-Up

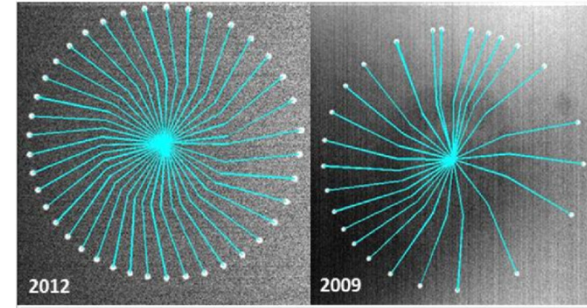
- Metrology Camera: QSI 540i CCD
 - 2048 x 2048 pixels, 7.4 μ m pixels
 - TEC-55 lens with 55mm extension tube
- Use translation stages to determine pixel scale (apparent motion vs. actual motion)
 - Near 1:1 (i.e. 4mm move on translation stage \approx 4mm move on CCD)
- Fiber image approximately 18 pixels across (133 μ m)
 - Sub-micron centroiding accuracy achievable
- Characterize the motor performance by moving a set number of steps and measuring the angle moved
 - Breaks the full range of motion into “regions”
 - Calculate the average step size in each region
 - Update average step size during testing
 - Average the average step size from the last move made with the existing average step size in that region
- Targets were randomly chosen over the full patrol area
 - 50 targets per Cobra



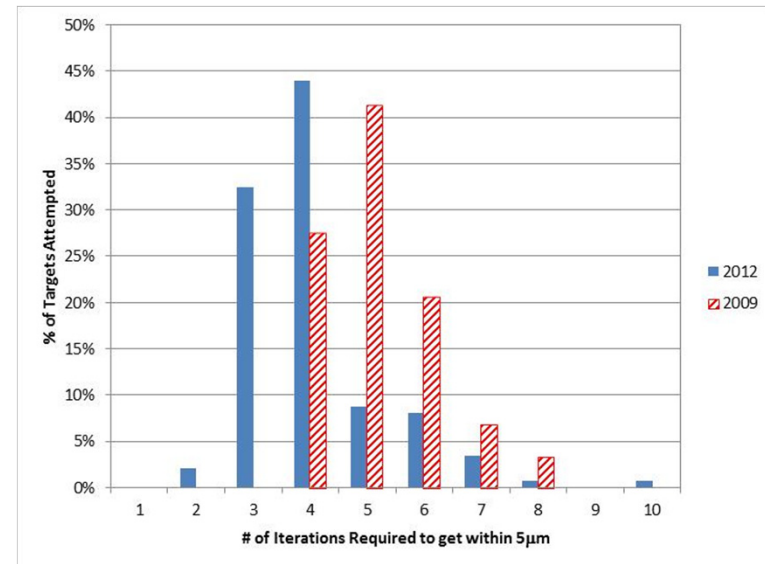
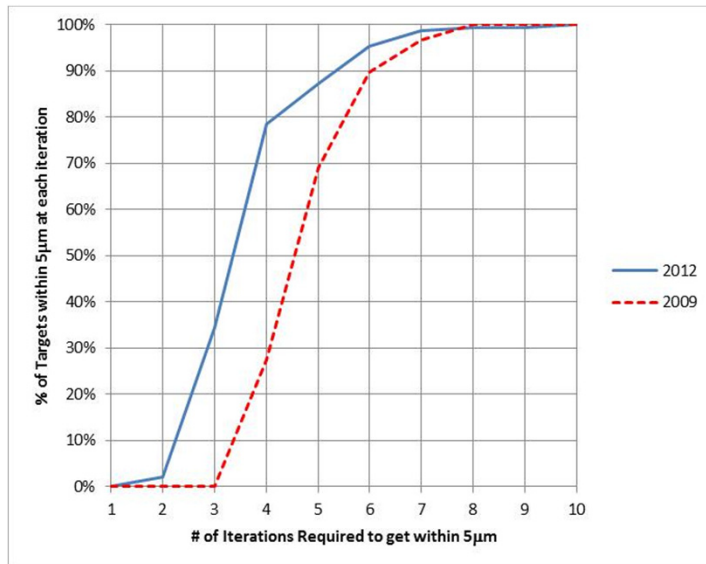
Performance Testing Results

- Design improvements resulted in a more uniform average step size for the motors

- Allowed for less iterations to move fiber to target



- 90% of all targets took 6 move iterations or less to get within 5 μ m
 - 95% took 7 move iterations or less
 - No correlation between move iterations needed and the distance the motors need to travel



Path Forward

- More developments planned to validate performance of the Cobra fiber positioner
 - Collision avoidance
 - Since patrol areas overlap care needs to be taken so that two adjacent positioners do not collide
 - Use 1-2 additional move iterations to move fiber to a staging area where final motion to target will be mostly radial
 - Running multiple Cobra's simultaneously
 - Software upgrades
 - Electronics
 - Initially use multiple MC-1000 boards from New Scale Technologies to run additional motors simultaneously
 - Test custom breadboard electronics that can run multiple motors from the same board

Summary

- The Cobra fiber positioner was re-designed based on lessons learned from the original development in 2009
 - Improved precision of ceramic motor parts
 - Eliminated the phi-stage floating hard stop
 - Elongated the theta-stage floating hard stop
- Performance improvements were realized
 - 1 less move iteration is needed to get 90% of targets to within 5mm compared to 2009 version
- The Cobra fiber positioner will enable PFS to make unprecedented red shift surveys of the universe.

